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Temporal trends in millet consumption in northern China

Pia Atahan [a], [*], John Dodson [a], Xiaoqiang Li [b], Xinying Zhou [b], Liang Chen [c], Linda Barry [a], Fiona Bertuch [a]

[a] Institute for Environmental Research, Australian Nuclear Science and Technology Organisation, Locked Bag 2001, Kirrawee DC, NSW 2232, Australia
[b] Key Laboratory of Vertebrate Evolution and Human Origin of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Science, 142 Xizhimenwai Street, Beijing 100044, China
[c] Institute of Archaeology, Northwest University, Xi'an 710069, China

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ABSTRACT

Temporal trends in prehistoric millet consumption are investigated in two regions of northern China, in the Wei River valley and a northern zone that encompasses north-eastern Shaanxi, western Shanxi and south-central Inner Mongolia. By directly radiocarbon dating each sample investigated, inferences about the timing of dietary shifts inferred from stable carbon and nitrogen isotope compositions can be made with a high degree of precision. Evidence presented here indicates that humans living around 4000 years ago in both the Wei River valley and the northern zone were heavily dependent on millet for their subsistence. By ca. 2500 cal. yr BP, a major diversification of diet had occurred in the Wei River valley, with some consuming much larger proportions of C3 foods than previously. These C3 foods may have included the western-derived cereals — wheat, barley and oats — and also rice.

1. Introduction

The means by which populations procure food has broad-ranging impacts on how societies develop and how the landscapes in which they live evolve. Few regions of the world have as long a history of agriculture as the middle and lower reaches of the Yellow River valley and few regions are dealing with impacts on land and water resources, related to agricultural activities, that are on such a grand scale (Sato et al., 2008; Saito et al., 2001; Liu and Xia, 2004; Tong et al., 2004).

Farming commenced in the Yellow River valley when the Asian millets began to be cultivated there around 10,000 years ago (Lu et al., 2009). Neolithic cultures persisted in that region until state-level societies and bronze age cultures were established at around the commencement of the second millennium BC (Liu and Chen, 2003, 2012). Neolithic cultures of the region utilised a mix of food sources. Archaeological investigations find remains of the Asian millets (*Panicum miliaceum* and *Setaria italica*) alongside remains of harvested and hunted wild foods such as nuts (*Corylus*, *Castanea*), molluscs and deer (e.g. Bettinger et al., 2010; Li et al., 2012, 2007b; Liu, 2004). Of the domestic animals present in this region, pig and dog remains are dominant for the Neolithic period, however remains of other domestic animals such as sheep/goat and cattle are also encountered (Barton et al., 2009; Chen et al., in press; Flad et al., 2007).

The suite of cultigens available to Neolithic farmers in northern China expanded with time. Seed assemblages indicate that rice (*Oryza sativa*), which has an origin in the Yangtze River valley to the south, had been adopted in the Wei River valley and lower Yellow River region by ca. 3000 BC (Lee et al., 2007). Buckwheat (*Fagopyrum* sp.) and soy bean (*Glycine* sp.), which may or may not have been a domestic variety, also appear to have been farmed (Li et al., 2007a). Wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and oats (*Avena* sp.), which originate in western Eurasia, are present in seed assemblages from Neolithic sites in northern China. The oldest firm evidence of these cereals come from sites in Gansu, Xinjiang and possibly Shandong, and date to around the mid to late third and early second millennia BC (Jin et al., 2011 in Betts et al., in press; Dodson et al., 2013; Flad et al., 2010; Li et al., 2011, 2007a). Recent reviews have explored potential routes by which these cereals were transmitted there (Betts et al., in press; Dodson et al., 2013; Flad et al., 2010).

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[*] Corresponding author.
E-mail addresses: atahansp@gmail.com, pia.atahan@googlemail.com (P. Atahan).

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By the time that state-level societies were established in the Wei River valley, commencing with the Erlitou (ca. 1900–1500 BC), a broadened suite of cultigens were available to farmers. Both archaeobotanical surveys (Lee et al., 2007) and stable isotope studies of human remains (Hou et al., 2012) indicate a gradual diversification of diet, away from a high dependence on millet, through pre-dynastic and early dynastic time periods. However, these periods have not received large amounts of attention by researchers interested in dietary reconstruction. This study aims to further understanding of temporal changes in millet consumption, from the Neolithic period to the later dynasties, and in parallel understand how the appearance of new C3 cultigens in the Yellow River valley affected diets. Unlike previous stable isotope studies focused on reconstructing diet, this study emphasises the importance of directly dating each bone sample analysed, in order to identify more precisely when large dietary shifts occurred. By directly dating the bone specimens themselves, precision surrounding sample age increases. With a high degree of certainty for the radiocarbon age of a sample, variability in stable isotope signatures can be better assessed to identify influencing factors, such as geographic location or social factors such as migration or gender.

2. Use of stable carbon isotope analysis to reconstruct diet in northern China

Stable carbon isotope analysis of bone remains is particularly useful for assessing past subsistence practices in northern China, as the principle prehistoric cultigens – the Asian millets – are C4 plants and thus contrast with the other pre-historic plant foods in their carbon isotope composition. Millet consumers can be distinguished by the ^{13}C-enriched nature of their remains. The method becomes more complicated in the Inner Mongolian steppes, where wild C4 plants are more abundant and are utilised by grazing and browsing herbivores (e.g. Auerswald et al., 2009; Wang, 2003).

The use of stable isotope analysis to distinguish millet consumption amongst prehistoric inhabitants of northern China has been described in detail by previous authors (e.g. Atahan et al., 2011; Barton et al., 2009; Chen et al., in press; Pechenkina et al., 2005). While estimating absolute proportions of millet plants or millet fed animals in ancient diets using bone δ^{13}C values can be problematic, due to the uncertainty surrounding isotopic composition of each food available to the individual during life. The method is useful for assessing changing proportions of dietary components through time and within populations. General categories for describing C3 and C4 food consumption in northern China have been developed: individuals with bone collagen δ^{13}C values ≤ -18‰ are typically interpreted to be mainly C3 food consumers; those with δ^{13}C values between -18‰ and -12‰ are interpreted to be mixed C3 and C4 food consumers; and those with δ^{13}C values ≥ 12‰ are interpreted to be mainly C4 consumers (Barton et al., 2009; Ma et al., 2014; Pechenkina et al., 2005).

3. Study regions

3.1. Wei River valley

The Wei River is the largest tributary of the Yellow River. It flows from west to east across modern-day Gansu and Shaanxi Provinces, before its confluence with the Yellow River near Tongguan. The Wei River valley is bordered to the south by the Qinling Mountains and to the north by the Loess Plateau. The climate of the area is characterised by cold dry winters and moist warm summers. Precipitation is strongly influenced by the East Asian Monsoon, and averages around 500–600 mm/year.

The earliest settled agriculturalists in the Wei River valley belonged to the Laoguantai Culture (ca. 8000–7000 BP). A low number of sites discovered to date result in relatively little being known about them, however existing evidence indicates that they were cultivating millet to provision both themselves and their domestic dogs and pigs with food (Barton et al., 2009; Bettinger et al., 2010). The Neolithic Yangshao (ca. 7000–5000 BP) and Longshan (ca. 5000–4000 BP) periods followed, after which the region was incorporated into the broad-reaching Erlitou state which had a centre in the Yiluo Basin to the east (Liu and Chen, 2012). The Wei River valley has played important political and cultural roles through the Chinese Dynasties. During the Western Zhou Dynasty (ca. 1100 BCE – 770 BCE), the capital was located at Fenghao to the south of modern-day Xi'an; and then during the Qin (221 – 206 BCE), Sui (581–618 CE), Tang (618–907 CE) and parts of the Han (206 BCE – 220 CE) Dynasties, the capital was located near to or at Xi'an (Lu and Yan, 2005; Xu, 2005). Currently large numbers of people inhabit the fertile alluvial plains of the Wei River, and many of these currently reside in large cities such as Xi'an and Baoji.

Samples from the Wei River valley region in the present study derive from six archaeological sites: Fenggeling, Lintong, Lixian, Xungyi, Yuhuazhai and Zhanguo. Small samples of bone were obtained from Northwest University's Institute of Archaeology collection. Site locations are shown in Fig. 1.

3.2. Northern zone

The northern zone here broadly refers to land following the southwards flowing section of the middle Yellow River, incorporating north-eastern Shaanxi, western Shanxi and south-central Inner Mongolia. The region has deeply incised river valleys and alluvial plains, sandy and loess dominated arid areas and elevated steppes. A strong precipitation gradient occurs from the southeast to the northwest of the region, spanning from around 500–600 mm/yr in the southeast and to around 300–400 mm/yr in the northwest.

Occasionally referred to as 'The Northern Frontier', this region is considered to have been a cultural and ecological transition zone since at least the emergence of state-level societies and bronze age cultures around 4000 years ago. Settled agricultural economies have traditionally dominated the climatically more moderate areas to the south, and nomadic pastoral or agro-pastoral economies have dominated the more arid steppe areas to the north (Huang and Su, 2009). The location of the boundary between these distinctly different economies appears to have been responsive to past changes in climate, whereby during moist periods when the summer monsoon was strengthened, agricultural societies expanded northwards, while during periods of drought or unstable conditions, the boundary moved southwards (Huang et al., 2002, 2003; Huang and Su, 2009; Zhou et al., 2012).

Bone samples from the northern zone were collected from five sites during part of a broader study on the ecological history of the region. The location of these sites – Dakou, Shimao, Xinhua, Xinhuacun and Zhukaigou – are shown on Fig. 1. Information about archaeological remains has previously been provided by Dodson et al. (2014), Flad et al. (2007), Linduff (1995) and Liu and Chen (2012).

4. Methods

4.1. Collagen preparation

Bone collagen from 27 samples of human bone was prepared for isotope analysis using the ultrafiltration method described by Brock et al. (2007), Bronk Ramsey et al. (2004), Brown et al. (1988) and

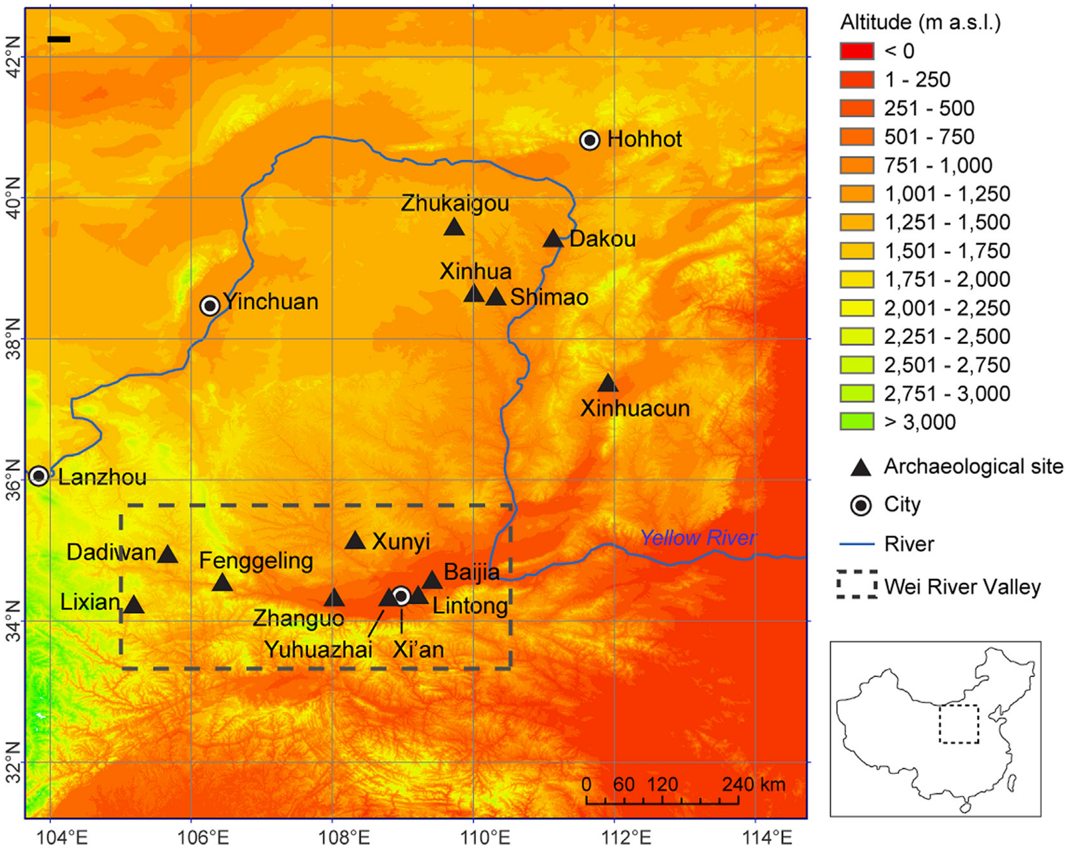

Fig. 1. Map of the Wei River Valley and the northern zone, showing locations of sites mentioned in the text.

Higham et al. (2006). Around one gram of bone was prepared after the outer layers of bone surface were removed in order to remove contaminants potentially introduced from the soil matrix. Sample preparation involved an acid-alkali-acid treatment (0.5 M HCl, 0.1 M NaOH); gelatinisation (pH 3, 75 °C, 20 h); Ezee-Filtration (4–8 μm); Ultra-Filtration (30 kDa); and freeze-drying.

4.2. Elemental analysis and isotope measurement

Carbon and nitrogen content and stable isotope ratios were determined using an Elemental Analyser (either a Vario Micro Cube or a EuroVector EA3000) linked to an IsoPrime Isotope Ratio Mass Spectrometer. The reference materials used were: IAEA C8 oxalic acid with a consensus δ^{13}C value of −18.3‰ VPDB (Gonfiantini et al., 1995; Le Clercq et al., 2006); IAEA N-2 with a consensus $\delta^{15}N_{AIR}$ value of 20.3‰ (Bohlke and Coplen, 1995); a 3:1 atomic ratio standard of 2-*iso*-propylimidazole; 'Chitin Organic Analytical Standard' with respective carbon and nitrogen values of 44.7% and 6.8% (Elemental Microanalysis Catalogue No. B2160) or 'IRMS Certified Reference Material EMA P2' with respective carbon and nitrogen values of 68.4% and 7.5% (Elemental Microanalysis Catalogue No. B2205); and an internal standard of undenatured bovine achilles tendon collagen. Samples were run in at least duplicate and the analytical precision for isotope measurements was mostly 0.2‰ for δ^{13}C values and 0.2‰ for δ^{15}N values. Samples OZM227, OZM228, SI2935/OZO953 and SI2942/OZO946 had a δ^{13}C precision of 0.3‰, SI2806/OZO871 had a δ^{13}C precision of 0.4‰, OZM229 and OZM232 had a δ^{15}N precision of 0.3‰ and OZM231 had a δ^{15}N precision of 0.4‰.

Collagen was graphitised for radiocarbon dating using standard procedures described by Hua et al. (2001). Radiocarbon content was determined by accelerator mass spectrometry at the Australian Nuclear Science and Technology Organisation. Radiocarbon dates were calibrated using IntCal13 calibration curve (Reimer et al., 2013) and the program Calib Rev 7.0.2 (Stuiver and Reimer, 1993). Calibrated radiocarbon dates mentioned in the text are presented with the post-fix 'cal. yr BP' and are rounded to the nearest 10 years.

4.3. Cluster analysis

Hierarchical clustering was conducted in R using the hclust package (R Core Team, 2014; RStudio, 2014). The two variables (δ^{13}C and δ^{15}N) were standardised using their median and their mean average deviation and the 'scale' function. Clustering was run using Euclidean distances and the 'complete linkage' method (see Kaufman and Rousseeuw, 2005).

5. Results

5.1. Collagen preservation

C%, N%, atomic C/N ratios and collagen yield (percent by weight) were used to assess the quality of collagen preserved in the bone samples. All samples produced C% and N% that were respectively greater than 43 and 15, and atomic C/N ratios fell between 3.2 and 3.5 (Table 1). These are within ranges deemed adequate for carbon and nitrogen isotope analysis (DeNiro, 1985; Van Klinken, 1999). Collagen yield was greater than 1% in all but one sample. A yield of 0.5% was recorded for sample OZM225 from Lixian, but given that the sample's other quality indicators were within acceptable ranges, it was included in this study. Overall the quality measurements indicated that collagen was well preserved within the

Table 1
Results for the elemental analysis, stable isotope analysis and radiocarbon dating on samples from the Wei River valley and the northern zone.

Site	Lab code	Museum reference	C (%)	N (%)	Atomic C/N	Yield[a]	$\delta^{13}C$	$\delta^{15}N$	^{14}C age (BP)	Calibrated age range[b]
Dakou	SI2940/OZO945	–	46	15	3.5	8.0	−7.6	6.8	3780 ± 40	4289–3991
Dakou	SI2942/OZO946	–	45	16	3.4	4.7	−10.2	8.2	3720 ± 45	4229–3926
Fenggeling	SI2806/OZO871	Stage 1 M2	45	16	3.3	1.6	−8.8	9.4	2335 ± 30	2438–2311
Fenggeling	SI2808/OZO872	Stage 2 M10	45	15	3.4	6.8	−9.0	8.5	2360 ± 30	2483–2332
Fenggeling	SI2809/OZO873	Stage 2 M11	45	15	3.4	8.8	−8.9	9.3	2335 ± 30	2438–2311
Fenggeling	SI2811/OZO874	Stage 3 M12	44	15	3.5	3.7	−9.9	9.0	2335 ± 30	2438–2311
Lintong	OZM222	07XLQM112	48	18	3.2	6.0	−15.7	10.4	2100 ± 35	2290–1954
Lintong	OZM223	07XLQM514	45	16	3.2	3.2	−9.5	9.9	2245 ± 30	2341–2155
Lintong	OZM224	07XLQM592	44	15	3.2	2.9	−16.3	8.0	1540 ± 30	1524–1365
Lixian	OZM225	05IT0105M1016	45	16	3.2	0.5	−14.1	8.9	2555 ± 35	2753–2496
Lixian	OZM226	05LXDIVT0106M4005	44	16	3.2	3.6	−16.5	9.0	920 ± 35	923–749
Lixian	OZM227	LXDIVT0101 M4002	45	16	3.3	1.0	−8.6	8.4	4035 ± 35	4782–4420
Shimao	SI2935/OZO953	–	45	15	3.4	1.2	−8.5	6.8	3515 ± 50	3921–3643
Shimao	SI2936/OZO954	–	45	16	3.2	2.4	−8.3	6.0	3570 ± 50	4057–3703
Shimao	SI2937/OZO955	–	46	16	3.4	5.4	−8.5	8.1	3540 ± 45	3963–3696
Shimao	SI2938/OZO956	–	46	15	3.5	2.0	−8.4	6.7	3555 ± 45	3971–3712
Xinhua	SI1595/OZN206	–	44	15	3.2	2.7	−8.7	8.2	3555 ± 35	3964–3720
Xinhuacun	SI2975/OZP089	–	45	16	3.2	6.9	−6.8	5.5	3785 ± 35	4287–4000
Xinhuacun	SI2976/OZP090	–	44	15	3.5	6.9	−7.8	7.5	3775 ± 30	4241–4007
Xungyi	OZM228	H76 (3)	44	15	3.2	3.8	−7.2	8.3	3765 ± 40	4245–3985
Xungyi	OZM229	H55	44	15	3.2	4.3	−7.2	8.1	3810 ± 35	4397–4087
Xungyi	OZM230	H78 (2)	44	15	3.2	4.7	−7.0	8.1	3750 ± 40	4235–3984
Yuhuazhai	SI2812/OZO875	M2	45	15	3.5	1.3	−9.0	8.2	4625 ± 35	5465–5297
Yuhuazhai	SI2816/OZO877	M6	45	16	3.4	2.5	−9.1	8.6	4945 ± 30	5729–5604
Zhanguo	OZM231	M263 200	43	15	3.2	4.9	−14.8	8.8	2350 ± 30	2461–2326
Zhukaigou	OZM232	–	44	16	3.2	5.1	−7.9	8.2	3680 ± 40	4145–3897
Zhukaigou	OZM221	–	44	16	3.2	6.0	−8.4	9.7	3500 ± 40	3877–3646

[a] Percent by weight of collagen recovered in the >30 kDa size range.

[b] Years BP according to the 2σ range estimated from the IntCal13 calibration curve (Reimer et al., 2013).

samples, and thus ante-mortem isotope ratios were likely to have been reliable.

5.2. Radiocarbon dating and stable isotope analysis

Radiocarbon ages for the samples ranged from 920 ± 35 ^{14}C yr BP for a sample from Lixian to 4945 ± 30 ^{14}C yr BP for a sample from Yuhuazhai (Table 1). All samples from the northern zone produced calibrated age ranges that fell within a time period of 640 years. These northern zone samples date to between ca. 4290–3650 cal. yr BP.

$\delta^{13}C$ values spanned a broad range from −16.5‰ for a sample from Lixian to −6.8‰ for a sample from Xinhuacun (Table 1). A smaller range was observed for $\delta^{15}N$ values which ranged from 5.5‰ for a sample from Xinhuacun to 10.4‰ for a sample from Lintong. The wide range in $\delta^{13}C$ values can be explained by differences in C4 food consumption.

5.3. Cluster analysis

A dendrogram produced by hierarchical cluster analysis shows how the samples can be separated into three main groups based on similarity of their $\delta^{13}C$ and $\delta^{15}N$ values (Fig. 2). The majority of samples lie within cluster 3, having $\delta^{13}C$ values that range from −10.2‰ to −7.0‰ and $\delta^{15}N$ values that range from 8.1‰ to 9.9‰ (Fig. 3).

Five samples whose $\delta^{13}C$ values are distinctly low, compose cluster 1. These samples derive from three sites in the Wei River Valley, and have calibrated ages within the range of ca. 2750–750 cal. yr BP. Samples in cluster 1 are amongst the youngest of the samples analysed in this study. Only five other samples fall within this age range. Based on their low $\delta^{13}C$ values, this group had diets with the smallest proportions of C4 foods.

Cluster 2 is composed of six samples that are depleted in ^{15}N in comparison to the other samples. These samples were collected from three sites in the northern zone and have calibrated ages between ca. 4290–3640 cal. yr BP.

6. Discussion

6.1. Stable isotope evidence for evolving diets

A temporal trend in $\delta^{13}C$ values is apparent for the samples analysed here. This trend is clear when $\delta^{13}C$ values are plotted with their calibrated age range (Fig. 4), and is retained when $\delta^{13}C$ values of three AMS ^{14}C-dated samples from the Wei River valley previously reported by Atahan et al. (2011) and Barton et al. (2009) are included. The trend is one for increasing $\delta^{13}C$ values to ca. 4000 cal. yr BP, and then decreasing $\delta^{13}C$ values to present. Only one sample in Fig. 4 predates 6000 cal. yr BP and this sample has a $\delta^{13}C$ value that is comparatively low (−14.5‰). The four samples with ages between 5000 and 6000 cal. yr BP have higher $\delta^{13}C$ values (mean = −9.9‰). The fourteen samples that have calibrated age ranges that fall around 4000 cal. yr BP have the highest $\delta^{13}C$ values, their mean $\delta^{13}C$ value is −8.0‰. The eight samples aged between 2000 and 3000 cal. yr BP have a very wide range in $\delta^{13}C$ values, spanning from −15.7‰ to −8.8‰, and have a mean of −11.8‰. Three samples that date to after 2000 cal. yr BP have the lowest $\delta^{13}C$ values measured. They have a mean $\delta^{13}C$ value of −15.9‰.

$\delta^{13}C$ values of samples dating to around 4000 BP are elevated, indicating that at this time humans were heavily reliant on millet or millet-fed animal products, in both the Wei River valley and in the northern zone. This time period is interesting from cultural and environmental perspectives. Around this time the northern zone was undergoing a transition away from an agricultural based economy associated with the Longshan culture and towards the mixed agro-pastoral economy of the Zhukaigou culture (Liu and Feng, 2012; Liu and Chen, 2012). In the Wei River valley, the culture was transitioning from the Neolithic Longshan to the state-level society of the Erlitou (Liu and Chen, 2003, 2012). Climate change is suggested to have played a role in these cultural transitions. Dryer conditions associated with a weakening of the summer monsoon are reported to have commenced around this time (Liu and Feng, 2012), along with a higher incidence of extreme flood events in the Wei River valley (Huang et al., 2010). In comparison to rice and wheat, millet is more productive in agriculturally marginal areas, it has a relatively short growing season and is capable of remaining productive during drought periods (Devi et al., 2011). Judging by the very high consumption of millet at this time, societies in both the Wei River valley and the northern zone were dependent on millet for their subsistence. And this may have been linked to the altered climatic conditions in which they were living. According to the evidence presented here, it was not until after around 2750–2500 cal. yr BP that a reduction in the dietary importance of millet is detected. And while this dietary shift is not observed in all samples of this age, this is the earliest indication of humans incorporating substantial proportions of C3 cultigens into their diet.

The samples investigated here indicate that a diversification of diet, away from a high dependence on millet, occurred just prior to 2500 cal. yr BP. Therefore, while the arrival of wheat and other western-derived C3 cereals in northern China represents a significant cultural event, this evidence from directly dated human remains suggests that there was a considerable time lag, of more than 2000 years, between their entry into northern China and their potential uptake as dietary staples. More human isotope values, particularly on remains dating to between ca. 3640 and 2480 cal. yr BP, are needed to verify the length of this apparent time-lag.

6.2. Diet patterns amongst investigated sites

Hierarchical cluster analysis was performed to determine whether the variability observed in stable carbon and nitrogen isotope measurements could be explained by difference in sample age or geographic location. Based on the isotope results, neither of

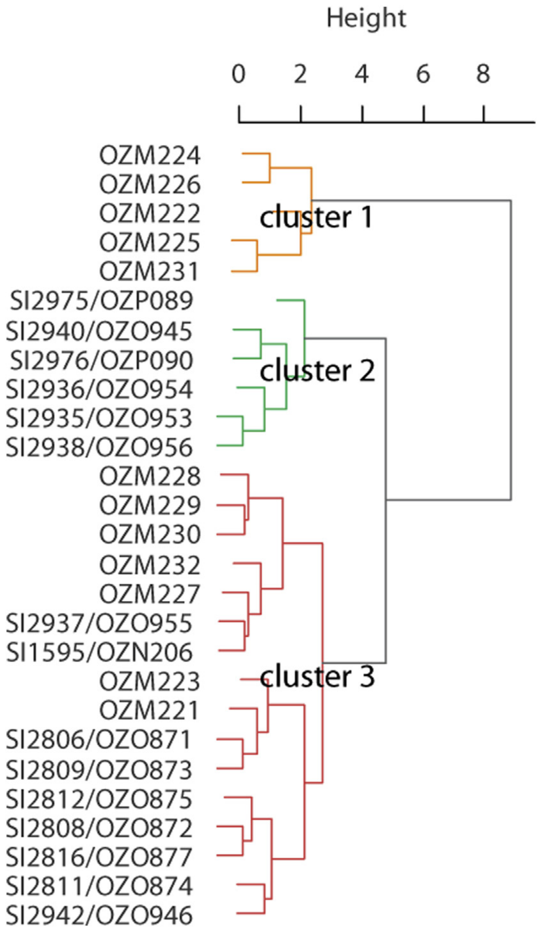

Fig. 2. Dendrogram produced by hclust (R Core Team, 2014; RStudio, 2014) showing three clusters of samples based on their δ^{13}C and δ^{15}N values.

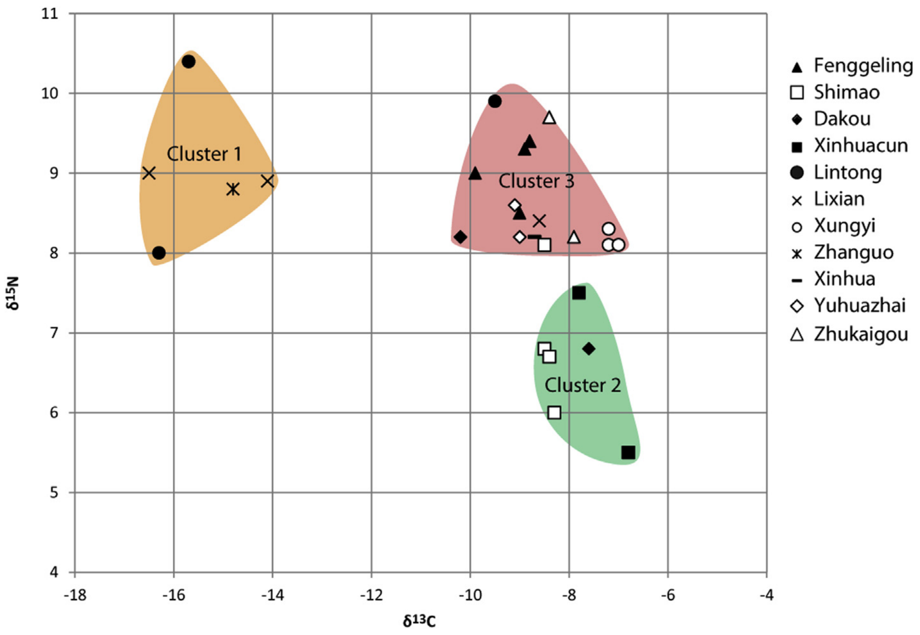

Fig. 3. Scatter plot showing with the δ^{13}C and δ^{15}N values, with three clusters marked by shading. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

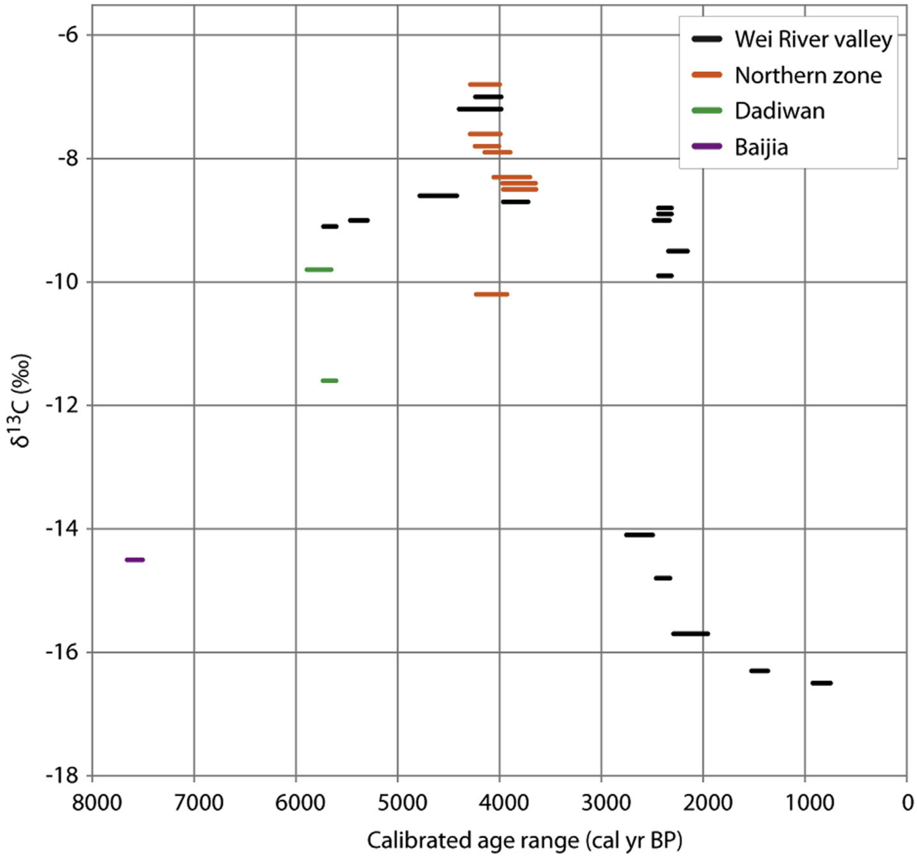

Fig. 4. Plot comparing $\delta^{13}C$ values and calibrated age ranges of human samples. Calibrated ages are the 2-sigma age range based on the IntCal13 calibration curve (Reimer et al., 2013). Samples shown here include isotope measurements on two human bone samples from Dadiwan site previously published in Barton et al. (2009) and one human bone sample from Baijia previously published by Atahan et al. (2011).

those factors entirely explains the diversity of observed $\delta^{13}C$ or $\delta^{15}N$ values. Samples from the same sites and of similar ages have remarkably differing stable isotope compositions (Fig. 3). It is apparent however, that samples with low $\delta^{15}N$ values only occur in the northern zone (cluster 2) and samples with low $\delta^{13}C$ values only occur in the Wei River (cluster 1). It is notable however that we do not consider samples from the northern zone that date to before 5000 yr BP or after 3000 yr BP, and these are time periods when low $\delta^{13}C$ values are observed in samples from the Wei River valley. The lack of human remains with low $\delta^{13}C$ values from the northern zone may thus be an artefact of the narrow time period represented by samples from that region.

The low $\delta^{15}N$ values observed in remains from the northern zone could have been produced by natural environmental conditions, lower application of manure fertiliser to millet crops, or lower consumption of animal foods. While reduced animal food consumption is seemingly at odds with the agro-pastoral nature of the Zhukaigou culture, it could reflect a more precarious existence for some in that region. Analysis of stable nitrogen isotope composition of individual amino acids has the potential to shed light on these potential causes, and represents an area for recommended future work.

The wide range in $\delta^{13}C$ and $\delta^{15}N$ values of samples from the same site and of similar age is surprising, and could potentially have resulted from: 1) some individuals spending extended periods in geographically distant areas, areas where certain foods such as cereals or animal products were available in different proportions, or the nitrogen isotope composition of plants at the base of food chains differed; or 2) diets at those sites were governed by social factors such as wealth or gender. The techniques employed in this study do not allow for these potential causes to be investigated further, but highlight areas for future attention. Employing other isotope techniques, such as Sr^{87}/Sr^{86} analysis, could help identify whether migration of certain individuals had occurred. Or alternatively, more information about archaeological contexts could identify signs of social difference within the specimens analysed.

7. Conclusion

This manuscript highlights the benefit of conducting radiocarbon dating directly on the bone collagen samples used for stable isotope analysis. With more certainty about the timing of dietary changes, other factors relating to regional difference or cultural change can be better compared. The small sample numbers for each site, coupled with a wide variation in stable isotope values for some of those sites, limit the significance of conclusions drawn here. Also the lack of samples dating to between ca. 3640 and 2480 cal. yr BP is a significant limitation of this study. However, the results that are available indicate that humans living in the Wei River valley and the northern zone around 4000 cal. yr BP were heavily dependent on millet for subsistence. By ca. 2500 cal. yr BP, diets in the Wei River valley had undergone considerable diversification, and by that time millet had been superseded as the principle staple food for some people. By ca. 2500 cal. yr BP, C3 foods were important dietary components for some people living in the Wei River valley and these foods may have included the western derived cereals (wheat, barley and oats) as well as rice.

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